Shifting Sands: Nonlinearity, Complexity and Randomness in Economics

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Abstract. The great crash of 2008 and the associated banking crisis have exposed the increasing irrelevance of much mainstream economics and provoked some economists to re-examine their discipline. Linear or linearised models with well-behaved additive stochastic disturbances, based on "microeconomic foundations" are no longer anywhere near adequate. Nonlinearity, complexity and randomness cannot be avoided, and the ideas of the British Emergentists have recently been given a new lease of life. Basing economics on algorithmic foundations provides a means of restoring genuine rigour to economics and, it is hoped, allowing the discipline to respond in a rational and humane way the next time a major crisis looms.

Keywords. Nonlinearity, complexity, randomness, emergence.

The CIFREM conference on nonlinearity, complexity and randomness took place at the University of Trento, Italy in October 2009, at the height of the financial crisis which was to lead most of the developed world into its most serious recession since the 1930's. A degree of soul-searching has taken place within Economics since then. With some honourable exceptions very

few mainstream economists foresaw the crisis or, if they predicted its financial genesis, failed to predict the dire economic consequences which were to follow. Economists' reactions have ranged from suggesting minor modifications to mainstream theory to completely rejecting it, and abandoning the Nobel Prize in Economics as an embarrassment to the profession (see Taleb, 2007). The context of this discussion is different from the crisis of the 1930's in that there is now a much wider public debate about economic problems and policy, a debate which has placed the Economics profession under close public scrutiny. Immediately before the Trento conference there was a public meeting in Bologna titled "Economists on Trial". History does not relate whether they were found guilty. In fact the prosecution could have laid two separate but related charges:

- The failure of mainstream economics to predict the banking crisis or to correctly analyse its relationship with the resulting recession.

- The contribution of mainstream economics to the construction of exotic financial derivatives[1] which were priced by mathematical models rather than by markets, and which played a central role in the failure of banks.

Some mainstream economists (the "honourable exceptions" mentioned above) have expressed doubts about the direction much orthodox theory has taken and its increasing irrelevance to the analysis of the real world. In his blog "The unfortunate uselessness of most 'state of the art' academic monetary economics" Willem Buiter (2009) comments:

“If one were to hold one’s nose and agree to play with the New Classical or New Keynesian complete markets toolkit, it would soon become clear that any potentially policy-relevant model would be highly non-linear, and that the interaction of these non-linearities and uncertainty makes for deep conceptual and technical problems. Macroeconomists are brave, but not that brave. So they took these non-linear stochastic dynamic general equilibrium models into the basement and beat them with a rubber hose until they behaved. This was achieved by completely stripping the model of its non-linearities and by achieving the transubstantiation of complex convolutions of random variables and non-linear mappings into well-behaved additive stochastic disturbances.

Those of us who have marvelled at the non-linear feedback loops between asset prices in illiquid markets and the funding illiquidity of financial institutions exposed to these asset prices through mark-to-market accounting, margin requirements, calls for additional collateral etc. will appreciate what is lost by this castration of the macroeconomic models. Threshold effects, critical mass, tipping points, non-linear accelerators - they are all out of the window. Those of us who worry about endogenous uncertainty arising from the interactions of boundedly rational market participants cannot but scratch our heads at the insistence of the mainline models that all uncertainty is exogenous and additive.”

The first lesson to draw from the current crisis within Economics is clearly that our models must embrace nonlinearity: linearised models with their saddlepoint dynamics and "jump variables" no longer serve any useful purpose (see George and Oxley, 1999 and 2008 for a detailed discussion of this point). Secondly, we need to revisit our analysis of randomness, uncertainty and rationality. The conference participants at Trento all addressed aspects of this agenda. They approached their topics from backgrounds in Economics, Physics, Computer Science and Philosophy, illustrating the *Journal's* founding principle, namely the need to escape the spurious specialisation of Economics and learn from other disciplines.

Discussion at the conference ranged from practical policy issues to methodological questions concerning the proper role for mathematical models in economics, and the appropriate type of mathematics upon which to base these models. Mainstream economists often justify their widespread use of mathematical modelling by appealing to the notion of intellectual "rigour". But this demand for rigour is not usually taken far: ask most economists if they subscribe to the Zemelo-Frankel axioms or the Axiom of Choice and you will usually get a puzzled response. However, these concerns were central for the Trento conference participants: much of the discussion concerned the possibility of an algorithmic basis for economics, particularly for nonlinear dynamics, and the computability of economic models. A theme of the conference was that the foundations of economics need to be recast in algorithmic terms. Most mainstream economics rests on a relatively narrow range of (largely 19th century) mathematical techniques such as optimisation

and linear algebra. But the foundations of mathematics itself have long been the subject of intense scrutiny, though many mathematicians have thought it best to consign these discussions to the separate discipline of Logic. However, these ideas cannot be kept in their box, not least because Turing's ideas and theorems (among others) have led directly to the 20th and 21st century revolution in computing. Ideas of computability, algorithms and constructive mathematics are now much more familiar than they were even thirty years ago. There are distinct potential advantages to be derived from developing algorithmic foundations for economics. For example, it would bring economic theory closer to the data against which theories must be tested, and hence closer to applied and policy analysis, which must be numerical and computational.

The perspective outlined above has both micro and macro economic dimensions. At the micro level the economist turns to bounded rationality and agent-based modelling. At the macro level s/he focuses on the theory of nonlinear dynamical systems and coupled markets, to which economists such as Goodwin (1947) made so many prescient contributions. From this type of macro-modelling one would hope to derive macro-policy prescriptions better adapted to dealing with global macroeconomic crises than the present, obviously inadequate, policy regime. At both micro and macro level there lurks the ever-present methodological danger of "reverse engineering". By this I mean deciding on an interesting or desirable outcome of a model and simply making the right assumptions to guarantee that outcome. It may not be necessary to (in Buiter's words) "beat them with a rubber hose until they

behaved" but economic models are often forced into a Procrustean bed of highly implausible and misleading assumptions. This is a particular temptation in macroeconomics, where dynamical systems theory is employed. This theory puts the focus on the classification of attractors of dynamical systems. For example strange attractors, which generate chaotic motion have appealed to economists but, this approach presents the temptation to reverse-engineer one's model in such a way as to generate the desired attractor. Concerns with the methodological unsoundness of this practice provide another reason to search for algorithmic foundations for nonlinearity, complexity and randomness.

This discussion leads naturally to a consideration of "emergence". Mainstream economics is characterised by a reductionist methodology. Macroeconomists are exhorted to provide "microeconomic foundations" for their models, an approach will yields some well-known conundrums. For example the microeconomists' most general and "rigorous" model, General Equilibrium, has no room for money or for the firm, something of an obvious weakness. Moreover, why stop at microeconomics? Fodor (1974) describes an 'immortal economist' who vainly tries to derive economic principles from a knowledge of physics and the distribution of physical qualities in space-time.The ideas of the British Emergentists (Mill 1843, Broad, 1925 and Alexander 1920) have been given a new lease of life recently via the theory of nonlinear dynamical systems. Discussion at the Trento conference focussed on the idea that emergent behaviour can be defined as behaviour which arises in the transition between the computable and the non-computable. It would be reasonable to

conclude that macroeconomics should discard its reductionist methodology and focus on the relationship between nonlinearity, complexity and emergence. It is distinctly possible that Goodwin would have approved such a programme. Velupillai (“Nonlinear Dynamics, Complexity and Randomness: Algorithmic Foundations”, this volume) asks how emergent behaviour can be generated from a dynamical system. His answer is that emergent behaviour should be defined as “that exhibited by the behaviour of a dynamical system in its *transition* from one that is incapable of computation universality to one that is capable of such universal behaviour”.

Nonlinearity, complexity and randomness are, for economists, inescapable. It has seemed to some that the present “rigorous” mathematisation of economics supplies a solid rock upon which to base their analysis and the policy prescriptions to which it leads. But “rigour” is a slippery concept and the basis of most mainstream economics is less solid rock, more shifting sands. Participants at the Trento conference, though disagreeing on many things, would probably argue that there is a way ahead, which puts economics and probability theory on an algorithmic basis, replacing sterile formalism with fertile formalism, and tackling seriously some of the methodological problems which have bedevilled economics. Let us hope that this work proceeds at a smart pace, so that next time a major crisis looms, economists have the tools to respond to it in a rational and humane way.

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[1] Warren Buffet's "weapons of financial mass destruction".